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STABILITY OF STRUCTURE FOLLOWING BIRD STRIKE

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TECHNICAL REPORT

MARCH 1966

by

Robert H. Ahlers

National Aviation Facilities Experimental Center

FEDERAL AVIATION AGENCY

AIRCRAFT DEVELOPMENT SERVICE

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SUMMARY

Standard tail surfaces from a piston-engine, turboprop and jet-type transport aircraft were subjected to bird strikes to determine the size of the bird that would cause structural failure when impacted at speeds ranging from 135 to 378 mph. Then the leading edges of the piston-engine and turboprop airplane stabilizers were modified by the incorporation of various structural reinforcements, and bird strike conditions used on the standard surfaces were duplicated to obtain a direct comparison of the vulnerability of the standard and modified structures.

Test results showed that the vertical stabilizer of the jet-type transport was the most resistant to bird strikes of all the tail surfaces tested; the stabilizer for the piston-engine aircraft was more resistant to bird strike damage than the standard stabilizer for the turboprop aircraft by virtue of having two load-bearing spars with other internal structure which more effectively absorbed the impact energy of the bird; and the stainless steel doubler was the most effective of the trial modifications made to the leading edge.

INTRODUCTION

Background

Past investigations and studies of bird strikes on aircraft in flight, led to the conclusion that no serious threat to aircraft safety existed when any part of the airplane, except the windshield, was struck by a bird. The only requirement that exists in the regulations governing airplane airworthiness, relative to bird strikes on transport category aircraft, is contained in Federal Air Regulations, paragraph 25.775.

This paragraph states that "Windshield panes directly in front of the pilots in the normal conduct of their duties, and the supporting structures for these panes, must withstand, without penetration, the impact of a four-pound bird when the velocity of the airplane (relative to the bird along the airplane's flight path) is equal to the value V_C (cruise velocity) at sea level." As a result of the findings of the Civil Aeronautics Board (CAB), after investigating a fatal crash of a transport airplane during November 1962, the bird strike problem appeared to extend beyond the windshield and its installation. The CAB concluded that the primary cause of the accident was the structural failure of the tail surface after striking a whistling swan in flight. With this experience of a structural failure caused by a bird strike, investigation of the vulnerability of structural parts, other than the windshields, became important. It implied that further investigation of the bird strike resistance of the airframe, especially the tail structure, was necessary. On older airplanes, propellers and wing positions provided some shielding of the horizontal tail surfaces from bird damage. Some current designs of high-speed airplanes place the horizontal tail surfaces high above the plane of the wing, and the change from piston to jet engines has eliminated the protective shield of the propeller. When airplane cruising speeds were low, bird strikes on the structure (other than the windshield) were not considered serious. However, as the cruising speed of modern-day airplanes continues to increase it is desirable to determine if a bird strike now presents a hazard to the airplane tail surfaces.

Purpose

The test program presented in this report was conducted to investigate the vulnerability of the airplane tail structure to bird strikes at the cruise speed of the airplane involved. A distinct phase of the test program was to determine the relative vulnerability to bird strikes of a piston-engine transport horizontal stabilizer which has two main spars versus a turboprop transport horizontal stabilizer which has one main spar. Also various types of modifications to the leading edge such as doubler plates, plastic foam fillers, splitter plates, and new-design leading edges, were incorporated to determine their effectiveness in increasing the resistance of the structure to bird strike damage. As an additional effort, the effect of speed reductions was investigated by impacting birds on a horizontal stabilizer at the turbulence penetration speed of the airplane, to compare bird damage at that speed against the normally higher cruise speed.

DISCUSSION AND RESULTS

Test Methods

The surfaces were mounted horizontally on a structural steel fixture which had a mass several times that of the surface itself to eliminate as much as possible any additional elasticity to the system. The test specimens were positioned in front of a 40-foot long gun, and the birds were shot out of the eight-inch diameter bore by means of compressed air. In general the stabilizer was struck near the tip and each successive strike was inboard of the last. Since these were mounted as cantilevers, a hit outboard causing structural failure would still allow further testing on the inboard structure, although it was not possible to ascertain how much the outboard strikes had strained or weakened the inboard structure. This procedure of multiple strikes on a structure was not felt to be detrimental to the overall objectives of the tests.

Before each test, the surfaces were incrementally loaded in the vertical bending mode and the deflection measured to obtain load versus deflection data in bending. The maximum load exerted at any given station during this test was kept below the design limit load so that the elastic limit of the structure was not exceeded. Therefore, the plotted data would be a straight line as long as the load testing remained within the elastic limit. This same load versus deflection procedure was repeated after each bird strike and if the data produced a straight line plot, it was an indication that the damage incurred had not weakened the structure of the stabilizers.

The design limit load of 30,000 pounds was used for the piston-engine transport and 16,000 pounds for the turboprop transport. This loading procedure could not be used on all test specimens because some of the tail surfaces were obtained from airplanes that had sustained crash damage. However, sufficient technique had been acquired from tests conducted previously where the load-deflection data were used, so that severity of the damage could be assessed visually without resorting to stressing these damaged structures. To supplement the bending load test, the surfaces were subjected to vibration tests. The surfaces were vibrated in two different axes by attaching a mechanically driven eccentric weight near the outboard tip. The spin axis of the weight was positioned perpendicular, then parallel to the leading edge of a tail surface, and the natural frequency was determined from these two modes of vibration by varying the speed of the rotating eccentric weight and recording frequency and amplitude on an oscillograph from six vibration sensors installed on the surface. The natural frequency was determined by selecting the frequency that had the greatest amplitude on the oscillograph record.

The natural frequencies of the surfaces were obtained before and after each bird strike. If the natural frequency had not changed and the load deflection plot discussed previously, had not deviated from a straight line, it was considered that the structural integrity of the surfaces had not been impaired.

The tail surfaces were mounted on the test fixtures in a cantilever fashion to simulate the actual aircraft installation with a chord-wise station in line with the air gun at the selected impact point. The distance between the gun muzzle and the leading edge of the surface was about 15 feet. Before the shot, the normal tail flight load at one g cruise speed, or the approved turbulence penetration for the aircraft, was applied by means of cables and pulleys. The tail balancing load for the piston-engine transport was determined to be 4230 pounds for a cruise speed of 300 mph and the tail balancing load for the turboprop transport at this same speed was 3200 pounds. For the turbulence penetration speed of 200 mph for the piston-engine transport, the tail balancing load was determined to be 5910 pounds.

The smaller birds used in the tests were loosely packaged in a plastic bag to more closely simulate a flying bird. To protect each bird from the forces developed during the firing cycle, the packaged bird was placed in a hollow cylinder of styrofoam which had an outside diameter slightly smaller than the airgun bore and a solid end against which the compressed air in the gun could act and propel the whole package through the gun. The speed of the package was controlled by varying the initial pressure of the air in the gun storage tank. However, because of the type of projectile used, the final speed of the bird package at impact varied slightly from test to test.

At the muzzle of the gun, a choke having a diameter slightly smaller than the styrofoam plug was installed to separate the bird package from the styrofoam, so that only the bird hit the target. The styrofoam hollow cylinder could not be used with birds weighing ten pounds and over because the resulting package would not fit into the eight-inch bore of the gun. Instead, the larger birds were put in a cloth bag and a serrated styrofoam plug was placed behind the bird package to protect it from the air pressure during firing. The plug was serrated so that it would break up into small pieces and would not contribute to the damage of the test specimen.

After the bird package left the muzzle of the gun, its speed was measured as it passed by and severed two wires that were positioned a known distance apart in its flight path. As the first wire was severed, an electronic counter was started by a pulse-producing network, and the second wire severed by the package stopped the counter. Knowing the distance between the wires and reading the time interval from the counter, the velocity of the bird could be calculated.

In addition to this method of speed determination, high-speed motion pictures were taken perpendicular to the flight path of the bird package as it left the gun muzzle. From the timing marks put on the film by a remote oscillator of known frequency, and the image of the package on the film passing measured distances, the speed of the bird was determined. There was good correlation between the two methods of measurement, and in addition, one method served as a backup for the other in case one failed.

High-speed motion pictures were taken of the impact area on the leading edge of the surface primarily to assess the damage caused by an abrupt rupture of the structure during a shot. The high-speed pictures were also of value to determine how the bird package struck the surface and to evaluate the mechanics of structural failure.

Piston-Engine Transport Stabilizer

The horizontal stabilizer of the piston-engine transport was the first specimen tested. The total span of this horizontal tail is 46.5 feet and is made up of a center section, which is an integral part of the fuselage tail cone, and a port and starboard outer panel. The outer panels are attached to the fuselage section at Station 62 (Station 0 is the fuselage centerline). Flight loads were applied to the structures undergoing test.

The first five bird strike tests on this tail surface were in the nature of exploratory shots, since no precedent was available which would allow a predetermination of the type and amount of damage the tail surface would sustain. Tests conducted at NAFEC and reported in Reference 1, indicate that there is no significant difference between the impact characteristics of freshly-killed fowl and various types of cut and ground meat. Therefore, the damage sustained by the tail surface on the fourth and fifth strikes, where ground meat was used in lieu of birds, may be taken as representative of the damage that would be sustained by a bird strike with the same weight and speed. The results of these strikes, as well as subsequent strikes on this stabilizer, are shown in Table I.

The rigidity of the structure was tested in bending and the structure was vibrated to determine its natural frequency. Figure 1 is typical of the results obtained in the bending load tests made at the various station locations on the tail surface. The load plotted in Figure 1 was applied at Station 99.25 and the deflection was measured at Station 105.75. Since the only bird strike made on the tail surface inboard of Station 99.25, prior to the time this bending test was made, was Test No. 1, Figure 1 is an assessment of the structural damage caused by Test No. 1. The plots of the data result in a straight line, which would tend to indicate that the structure remained within the elastic limit. Also, from the vibration test it was determined that the natural frequency of the structure had not changed sufficiently, after Test No. 1 to indicate that any deterioration of structural strength had occurred.

All of the load-deflection data resulted in a straight line, indicating that the structure of the tail surface remained within the elastic limit as a result of sustaining nine bird strikes.

The effect of speed reduction on bird impact vulnerability was also investigated. Eight bird strikes, at the "turbulence penetration speed" of the airplane, were made on the third test specimen. The first two strikes were with eight-pound birds which did no damage to the leading edge at these lower impact speeds. The third strike was with a ten and one-half-pound bird and the structure withstood this strike at the lower speed of 156 mph., whereas the same size bird caused structural failure at 298 mph. None of the other bird strikes, made on this test specimen at the slower turbulence penetration speeds, caused critical damage except the last two which were birds weighing 14.2 pounds. The carcass of these larger birds would not physically fit between the spar caps which resulted in distortion and fractures of the spar caps as shown in Figures 3 and 4.

Piston-Engine Transport Stabilizer (Modified)

In an effort to decrease the vulnerability of the horizontal tail surface to bird strike damage, several modifications to the leading edge were incorporated. Table II contains a summary comparison of the results of the bird strikes made against the modified tail surface as well as the unmodified one, and Figure 5 shows the modified stabilizer after the bird strike tests had been completed on it.

An aluminum structural angle splitter was installed behind the leading edge of the tail surface where Test No. 23 was made. The impact load taken up by the structural angle was transmitted to the outboard support and then to the spar caps to which the support was attached. This load transfer to the spars caused them to be severely distorted and the failure of the weld, which connected the structural angle to the support, allowed the structural angle to sweep back in an arc and tear out more of the internal structure than was the case for the unmodified structure. It was judged that this modification actually increased, rather than decreased, the vulnerability of the structure to bird strike damage.

The leading edge section on which Test No. 25 was made had a stainless steel doubler 0.100 inch thick, and a plastic foam filler in the D section of the leading edge. The stainless steel doubler successfully stopped the bird from penetrating the leading edge. Since the stainless steel doubler was attached to the front spar caps by a row of bolts, the impact energy was transferred from the doubler to the rest of the structure through several points and there was no localized failure of the structure, as was the case on Test No. 23.

For Test No. 26 the section of the leading edge had an 0.100 inch stainless steel doubler backed up by an aluminum structural angle. The modification prevented the bird from penetrating the leading edge. The impact load was transferred from the stainless steel doubler to the front spar caps and there was some buckling of the external skin, but the structural strength of the surface was not seriously affected by this bird strike.

On Test No. 27 the section had the original standard aluminum leading edge backed with a plastic foam filler. The bird penetrated the leading edge, distorted the front spar caps, and passed completely through the rear spar web. This modification was completely ineffective and this bird strike caused structural failure just as it did on the unmodified tail surface.

Turboprop Transport Stabilizer

The horizontal stabilizer from a turboprop transport in the 300 mph regime was the second type of structure tested. The length of each half of the stabilizer was 189 inches, measured from the surface root where it joins the aircraft fuselage. For identification purposes, the surface root was considered to be Station 0 and the outboard tip was Station 189.

One "g" balancing tail loads were applied for these tests. Five bird strikes of various weight birds were made on the unmodified structure at impact speeds of approximately 300 mph. Table III is a summary of these strikes.

The structural integrity of the tail surface was not impaired by any of these strikes except Test No. 32. On this last one the bird went completely through the stabilizer, cut the elevator in two and tore off the elevator trim tab. The spar was severely damaged and the tail surface lost all structural strength. Figure 6 is a load-deflection curve of Test No. 31 and is representative of the three previous strikes where structural failure did not occur. Figure 7 is a plot of the load-deflection data taken after Test No. 32 where the deflection increased with decreased load indicating structural failure of the stabilizer.

Turboprop Transport Stabilizer (Modified)

Three modifications to the leading edge of the horizontal stabilizer were made to increase its resistance to bird strike damage. The original leading edge is made of two layers of aluminum skin separated by a distance of 0.135-inch by stringers to allow hot air to flow between them for de-icing the leading edge. A typical cross-section of the standard leading edge is shown in Figure 8. The three modifications to the leading edge consisted of a laminated stainless steel splitter plate behind the original leading edge, as shown in Figure 9; a stainless steel leading edge to replace the aluminum, with the addition of two stainless steel webs, as shown in Figure 10; and a stainless steel doubler over the existing leading edge, as shown in Figure 11. Each modification was about four feet long and all were incorporated on one horizontal surface.

The modified stabilizer was subjected to bird strikes that were similar in bird weights and speeds to those performed on the unmodified structure, to determine the effectiveness of the modifications. A summary of these strikes is included in Table III.

Figure 12 is an overall view of the modified stabilizer after it had been struck by the four birds. The modifications were effective in preventing bird penetration but the energy of impact was transferred to the structure behind the leading edge, causing it to buckle. The modifications prevented bird penetration and therefore, protected the rear spar, which is the main structural member of this type of airfoil construction.

Jet-Type Transport Stabilizer

Bird strikes were made against a vertical stabilizer and a horizontal stabilizer of a modern high-speed transport jet airplane. Eight bird strikes of various weights, ranging from 11 to 14 pounds, were made on the vertical stabilizer at impact speeds of about 300 mph. Table IV is a summary of these strikes. Figure 13 is an overall view of the surface after the eight bird strikes had been made.

Tests Nos. 41 to 44 were a series of strikes made where bird weight and impact speed were kept constant but the impact locations were changed. The first shot of this series was made at the furthermost inboard location 216 inches from the surface tip. The bird penetrated the leading edge but did not damage primary structure, and therefore, this strike did not weaken the structure. The impact point of the next shot (Test No. 42) was outboard of the last strike and the bird did not penetrate the leading edge as much. The next two strikes were successively farther outboard and leading edge penetration became less as the impact moved farther outboard on the tail surface. On Test No. 44 the impact did no damage to the leading edge. A series of four bird strikes were made on the horizontal stabilizer of the jet-type carrier transport. A summary of these strikes is given in Table V. Figure 14 is an overall view of the horizontal stabilizer after the four bird strikes had been made. On all of these strikes, the bird penetrated the leading edge and tore out internal structure and ribs before becoming lodged inside the structure. Although the birds penetrated the structure, the spar caps were undamaged and therefore, the structural strength was not impaired. It appears from the above tests that the horizontal stabilizer was not as resistant to bird strike damage as the vertical stabilizer. A ten-pound bird at about 300 mph impact speed easily penetrated the leading edge of the horizontal stabilizer at any location along its length, whereas the vertical stabilizer withstood a 14-pound bird impacting at 300 mph penetration, if the strike was made toward the outboard tip. If the horizontal stabilizer could be manufactured more along the lines of the vertical stabilizer, it appears that it might be less vulnerable to bird strike damage.

CONCLUSIONS

It is concluded that:

1. The jet powered aircraft horizontal stabilizer has the best bird penetration resistance of the horizontal stabilizer specimens tested.

2. The piston powered aircraft two spar horizontal stabilizer has greater bird penetration resistance than the single spar turboprop powered aircraft horizontal stabilizer.

3. The jet powered aircraft vertical stabilizer has greater bird penetration resistance than the horizontal stabilizer.

4. Modifications which increase the strength to prevent bird penetration are more desirable than modifications to increase ability to absorb energy.

5. Decreasing airplane speed when flying in known bird areas is effective in decreasing bird penetration if a strike occurs.

6. Bird strikes close to the root of the surface tend to pass between the spar caps, producing less damage and attendant decrease in structural strength than strikes closer to the tip.

7. Thin airfoil sections such as found nearer the tip of the surface tend to deflect under impact rather than absorb the bird impact, resulting in less damage to the surface.

REFERENCE

Sommers, John Jr.: Tests of Materials and Packaging Methods for Use in Aircraft Windshield Bird-Impact Simulation, Federal Aviation Agency, Aircraft Development Service Technical Report ADA - 23, August 1964

TABLE I

SUMMARY OF BIRD STRIKE DATA ON THREE PISTON-ENGINE TRANSPORT HORIZONTAL STABILIZERS

TEST No.	BIRD WEIGHT	IMPACT VELOCITY	TARGET STATION	SIMULATED AIR LOAD		TEST LOAD		NATURAL FREQUENCY		REMARKS
	Pounds	mph	in	LOAD	STATION	LOAD	STATION	BENDING	TORSION	
				lb	in	lb	in	cps	cps	
1	5	303	90	-	-	4400	99.25	8.2	24.0	Penetrated the leading edge but
2	5	297	244.5	-	-	610	244.5	8.2	24.0	the structural strength was not
3	5.3	279	262	-	-	-	-	8.2	24.0	seriously impaired
4	3	255	230	-	-	610	244.5	8.2	24.0	
5	5	292	208	-	-	610	244.5	8.2	24.0	
6	5	274	179	680	189	1120	190.5			Glanced off leading edge
7	4.2	269	179	680	189	1120	190.5			
8	3.9	295	152	910	162	1120	190.5	7.9	20.5	Penetrated the leading edge but
9	6.75	274	113.5	1250	123	3600	129.5	7.9	20.5	the structural strength was not
10	8	297	236	230	246	1325	251.75			seriously impaired
11	8	311	172	760	182	3525	186			
12	10.5	298	152	910	162	3400	189.3			Structural failure
13	13.9	284	122	1180	132	-	-			Penetrated leading edge
14	14	301	197	560	207	-	-			Structural failure
15	8	138	236	320	246	-	-			No damage
16	8	160	236	320	246	-	-			
17	10.5	156	152	1270	162	-	-			Slight dent leading edge
18	8	135	172	1060	182	-	-			No damage
19	8.25	199	236	320	246	-	-			Dent and tear leading edge
20	7.75	205	172	1060	182	-	-			Penetrated leading edge
21	14.2	193	197	780	207	-	-			Structural failure
22	14.2	208	122	1650	132	-	-			

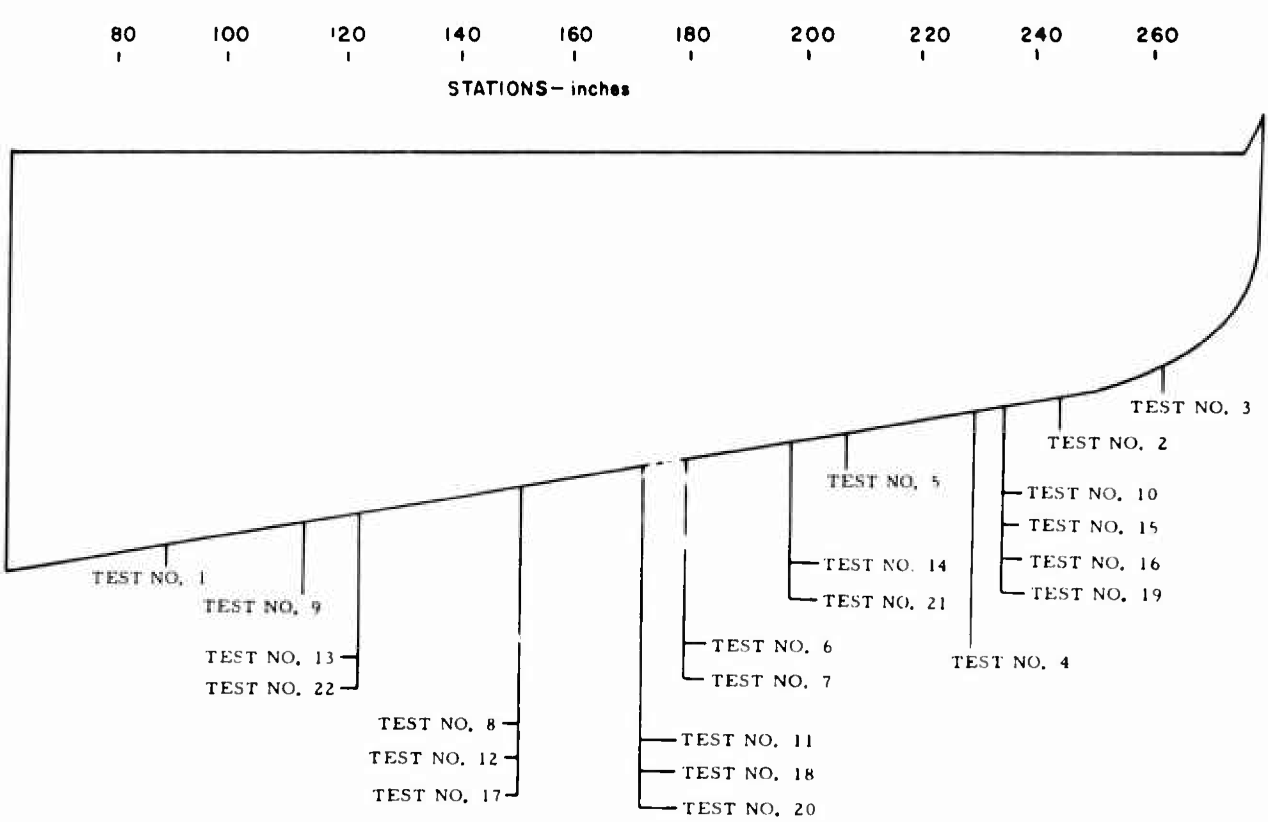


TABLE II

SUMMARY OF BIRD STRIKE DATA ON AN UNMODIFIED AND A MODIFIED PISTON-ENGINE TRANSPORT HORIZONTAL STABILIZER

TEST No.	BIRD WEIGHT Pounds	IMPACT VELOCITY mph	TARGET STATION in	SIMULATED AIR LOAD Pounds	REMARKS
	Unmodified Structure				
10	8	297	236	230	Structural strength was not seriously impaired
11	8	311	172	760	Structural strength was not seriously impaired
12	10.5	298	152	910	Caused structural failure
13	13.9	284	122	1180	Structural strength was not seriously impaired
14	14	301	197	560	Caused structural failure
	Modified Structure				
23	8	315	236	230	Slight weakening of structure
24	8	217	172	760	No effect on structural strength
25	10.5	307	152	910	No penetration of leading edge. Structural integrity maintained
26	14	301	122	1180	No penetration of leading edge. Structural integrity maintained
27	14	291	197	360	Caused structural failure

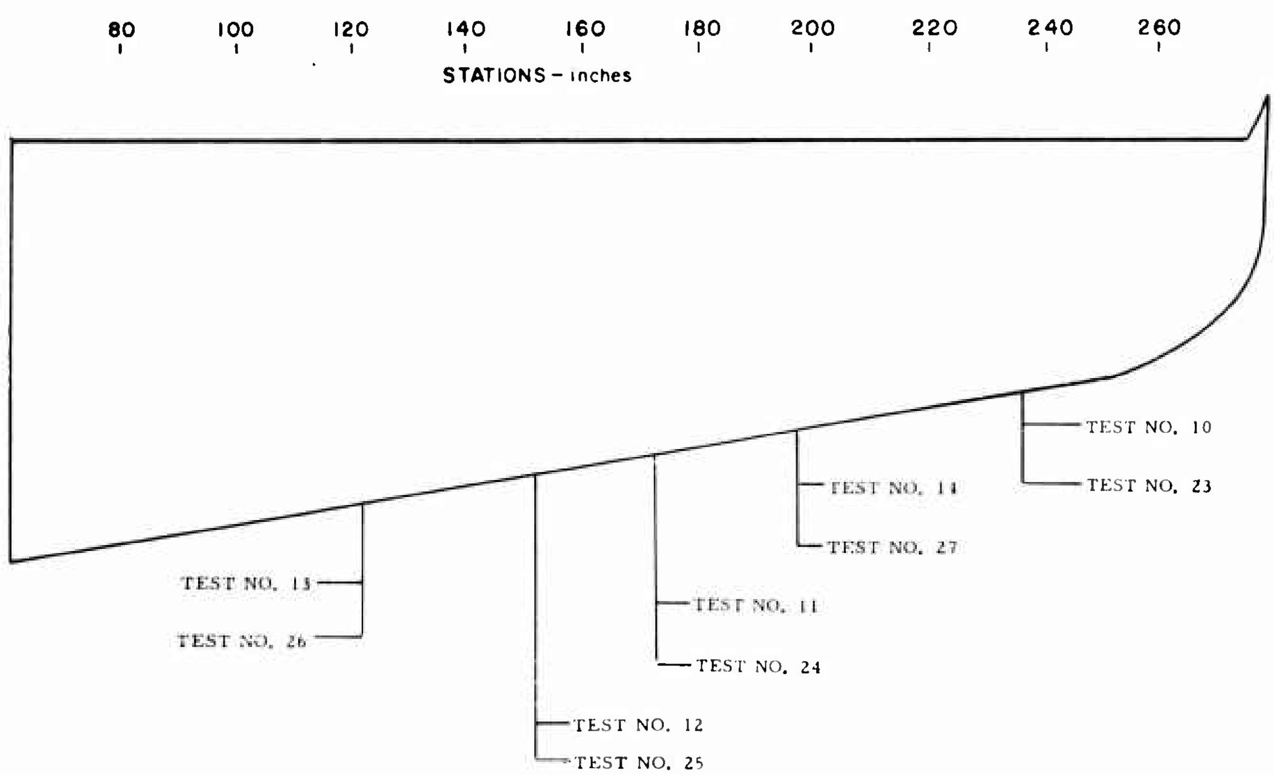


TABLE III

SUMMARY OF BIRD STRIKE DATA ON AN UNMODIFIED AND A MODIFIED TURBOPROP TRANSPORT HORIZONTAL STABILIZER

TEST No.	BIRD WEIGHT Pounds	IMPACT VELOCITY mph	TARGET STATION in	SIMULATED AIR LOAD Pounds	REMARKS
		Unmodified Structure			
28	4	257	112	1210	Penetrated leading edge but did not cause structural failure.
29	6	278	90	1560	Penetrated leading edge but did not cause structural failure.
30	5.9	310	56.5	2160	Penetrated leading edge but did not cause structural failure.
31	8	325	38	2470	Penetrated leading edge but did not cause structural failure.
32	8	324	102	1350	Caused structural failure
		Modified Structure			
33	4	285	112	1210	Did not penetrate leading edge, structural integrity of structure was maintained.
34	6	289	90	1560	Did not penetrate leading edgo, structural integrity of structure was maintained.
35	8	313	38	2470	Leading edge penetrated but rear spar protected from strike by splitter plate. Structural integrity of structure was maintained.
36	6	289	133	800	Did not penetrate leading edge, structural integrity of structure was maintained.

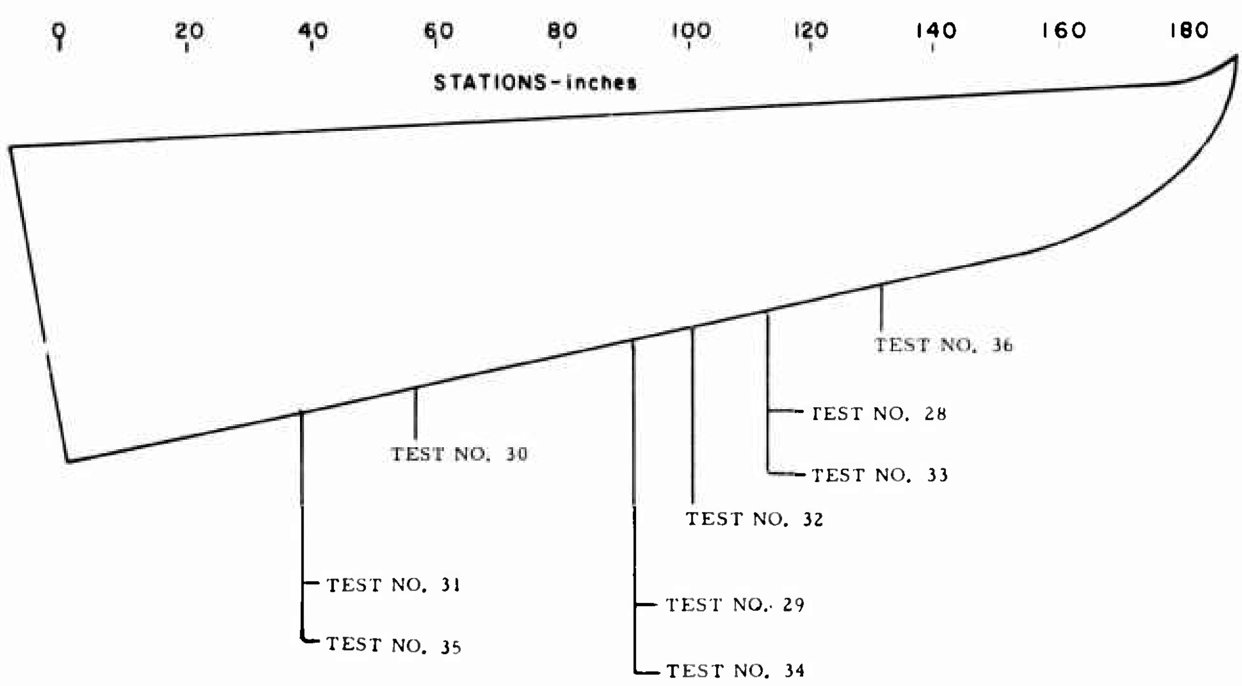


TABLE IV

SUMMARY OF BIRD STRIKE DATA ON A JET-TYPE TRANSPORT
VERTICAL STABILIZER

TEST No.	BIRD WEIGHT Pounds	IMPACT VELOCITY mph	DISTANCE OF IMPACT POINT FROM TIP in	REMARKS
37	14	287	24	The first two bird strikes did no damage
38	10.75	302	72	
39	14	293	72	De-icer boot damaged; primary structure sound
40	14	378	24	Dent 3/4 inch deep in leading edge
41	11.1	293	216	Leading edge crushed by impact but primary structure remained unharmed
42	11.5	309	186	
43	11	296	147	Leading edge dented
44	11	300	123	No damage

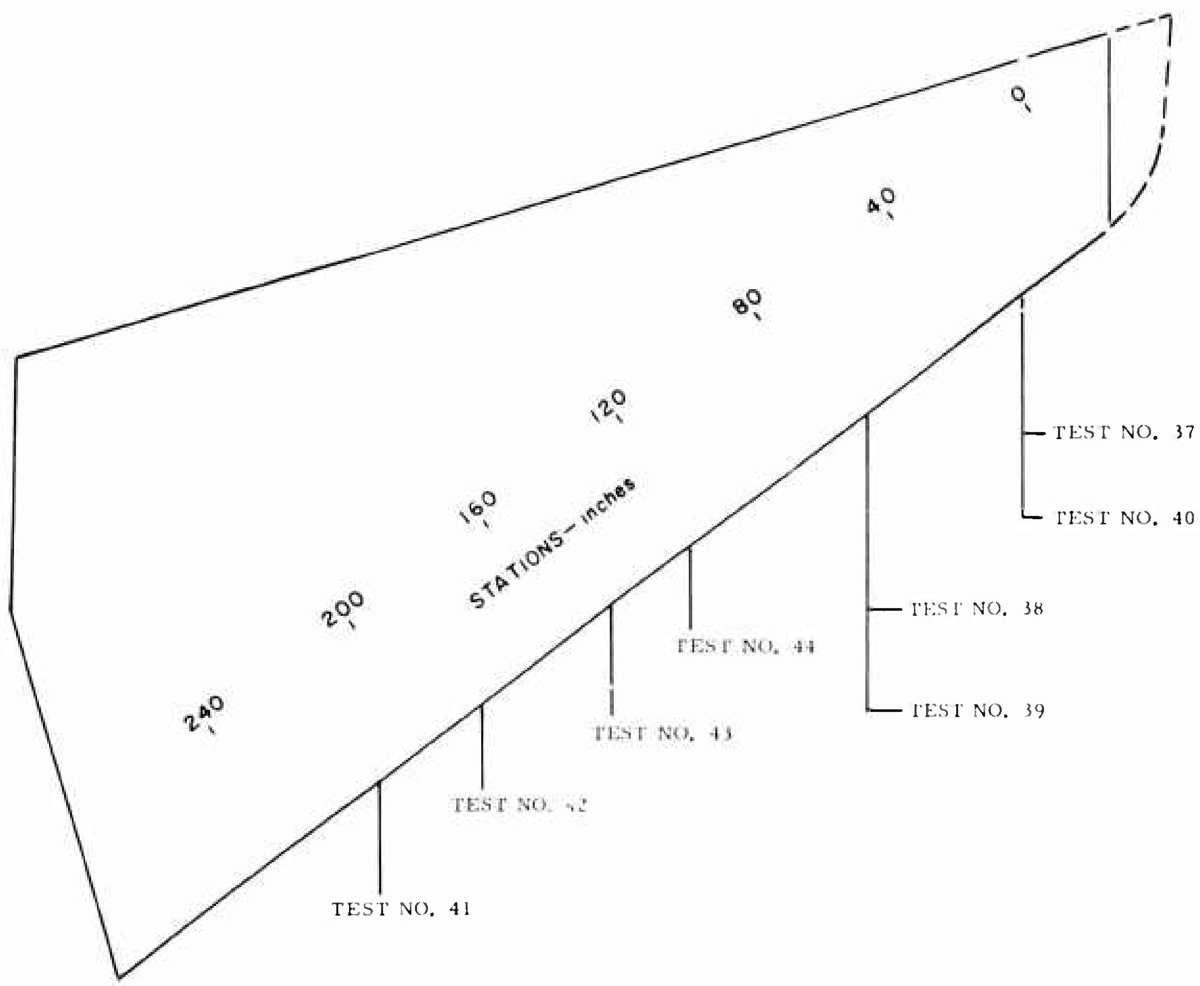
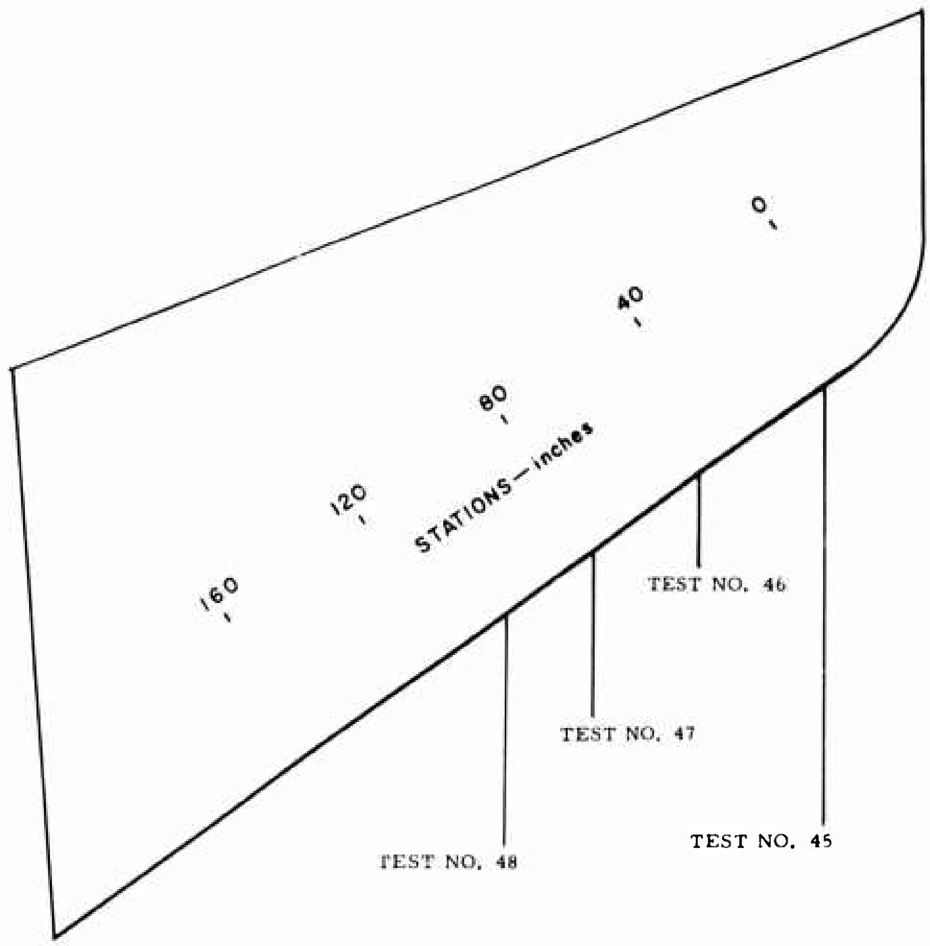


TABLE V

SUMMARY OF BIRD STRIKE DATA ON A JET-TYPE TRANSPORT HORIZONTAL STABILIZER

TEST No.	BIRD WEIGHT Pounds	IMPACT VELOCITY mph	DISTANCE OF IMPACT POINT FROM TIP in	REMARKS
45	9.25	294	12	On all of these shots the bird penetrated the leading edge, tore out internal ribs, and remained lodged inside the stabilizer. Spar caps were undamaged.
46	9	304	48	
47	10	305	80	
48	10.75	300	106	



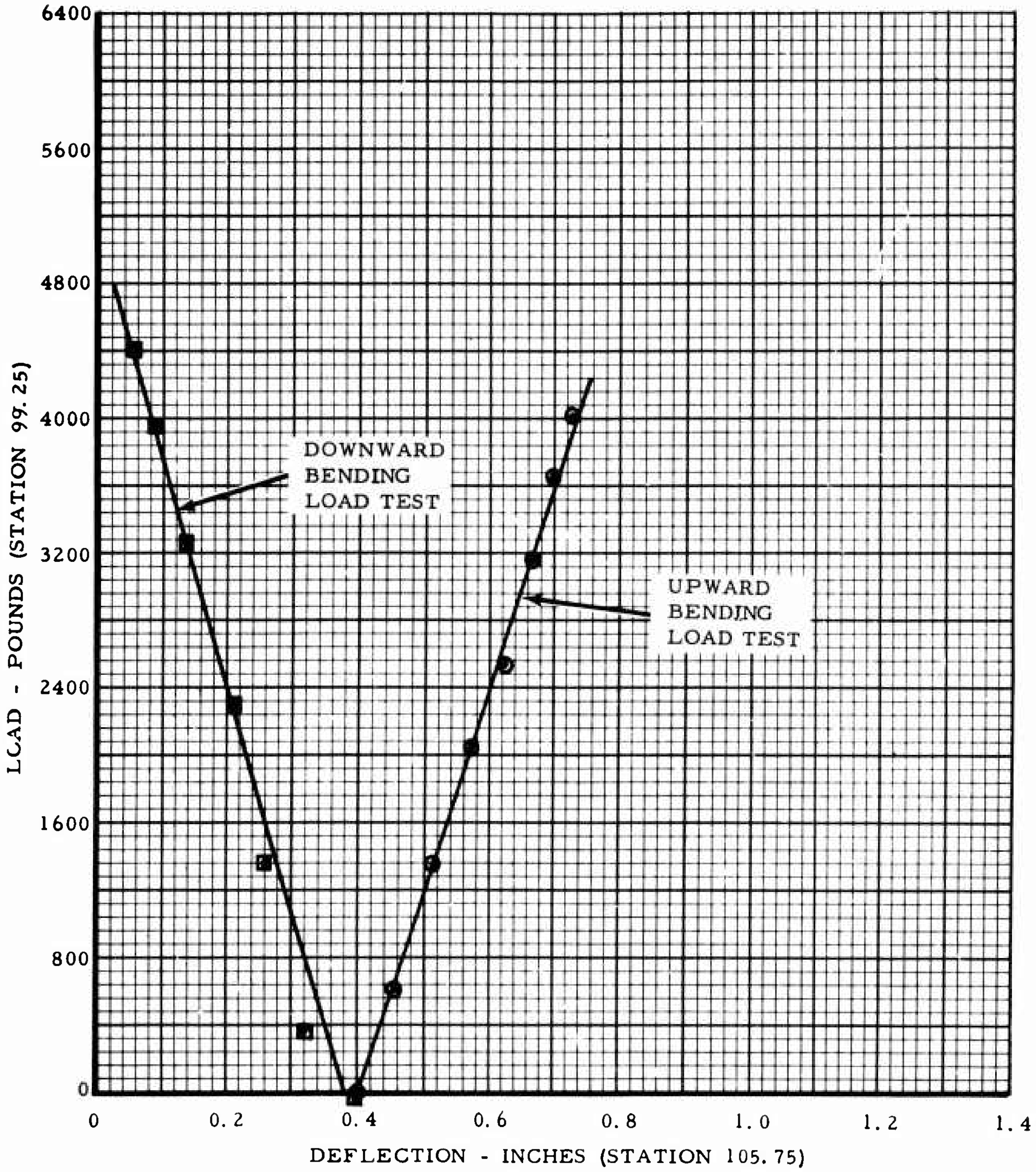


FIG. 1 TYPICAL LOAD-DEFLECTION TEST RESULTS ON A PISTON-ENGINE TRANSPORT AIRPLANE HORIZONTAL STABILIZER

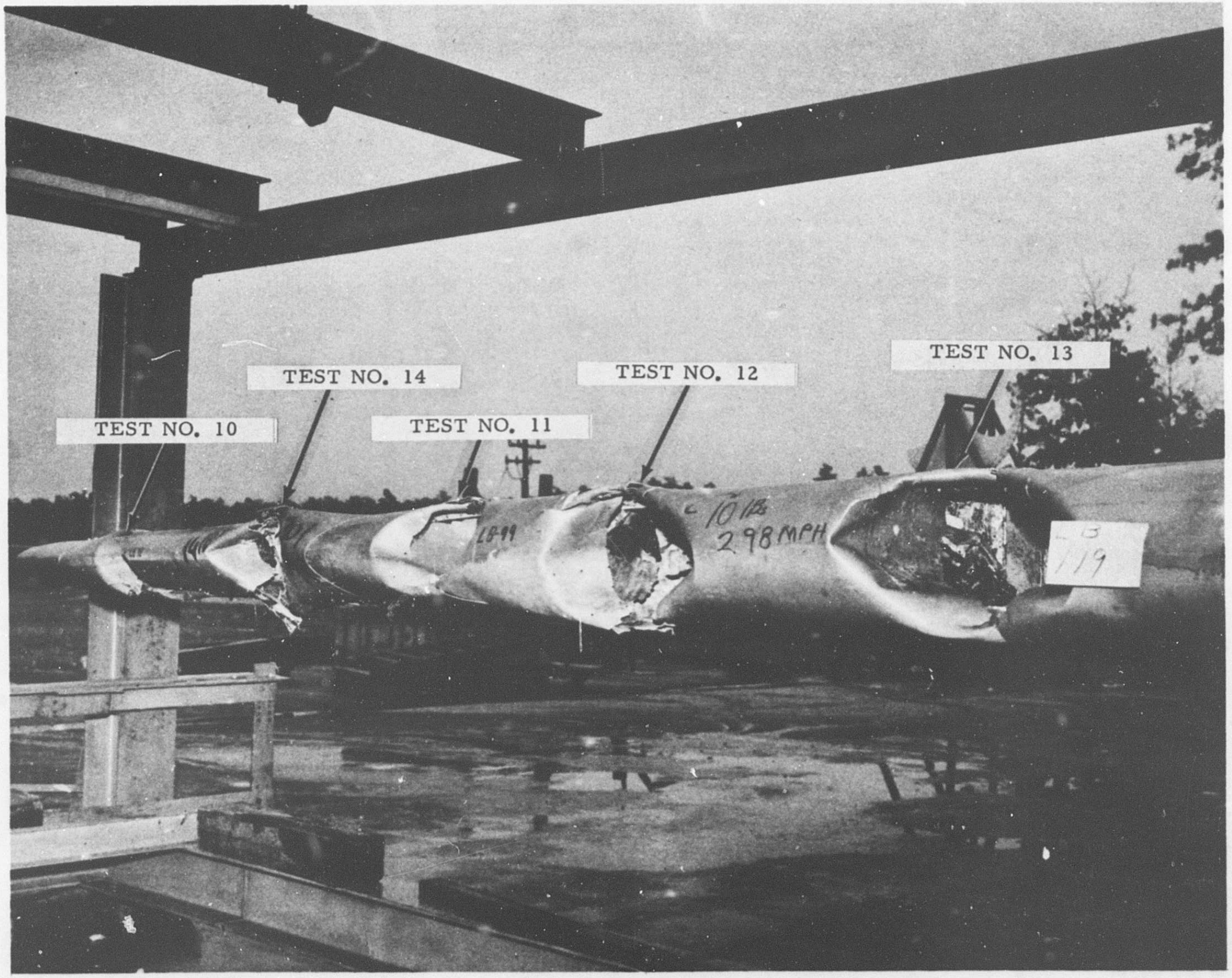


FIG. 2 BIRD STRIKE RESULTS ON SECOND TEST SPECIMEN OF A PISTON-ENGINE TRANSPORT HORIZONTAL STABILIZER

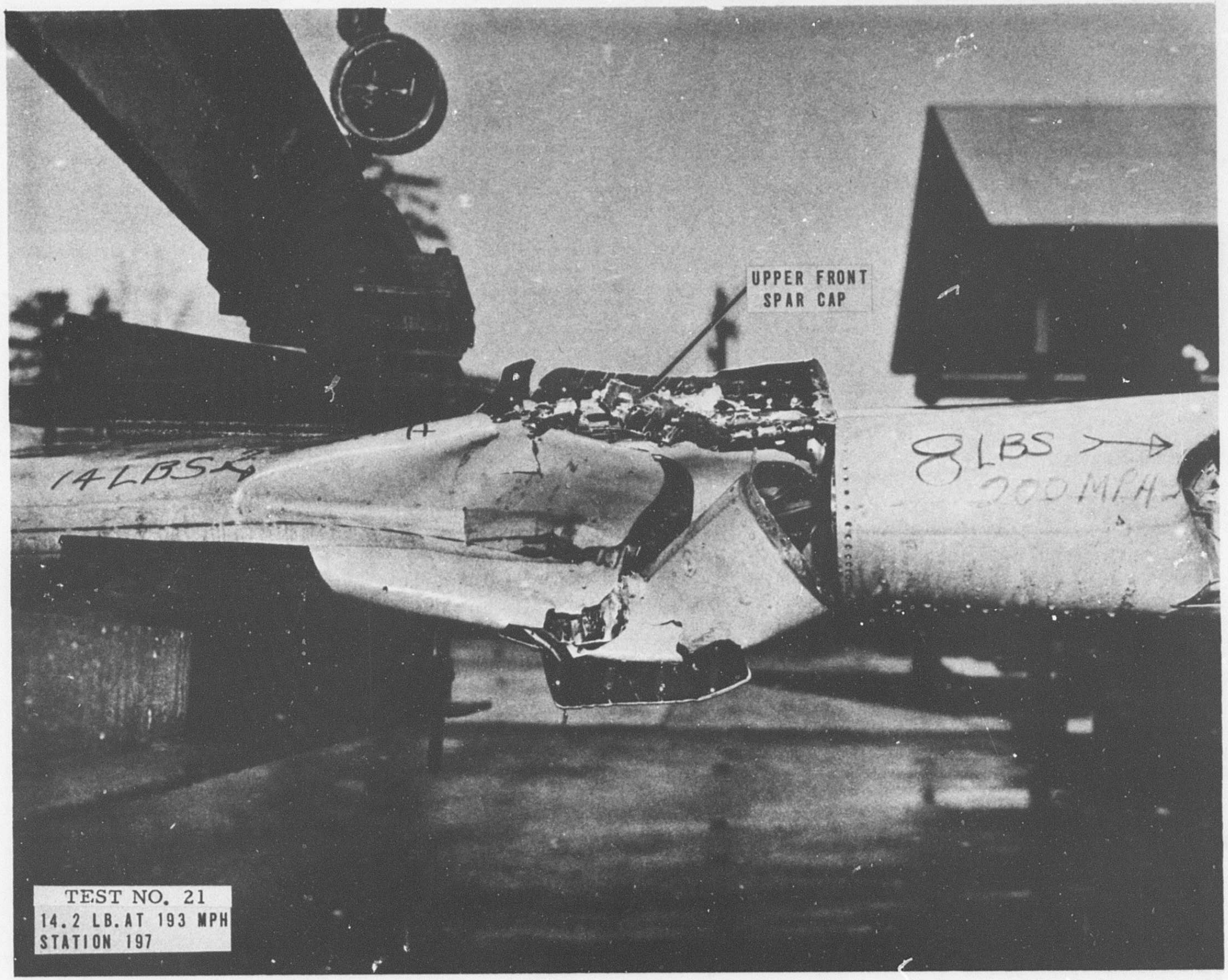


FIG. 3 BIRD STRIKE DAMAGE TO LEADING EDGE OF THE HORIZONTAL STABILIZER OF A PISTON-ENGINE TRANSPORT AIRPLANE

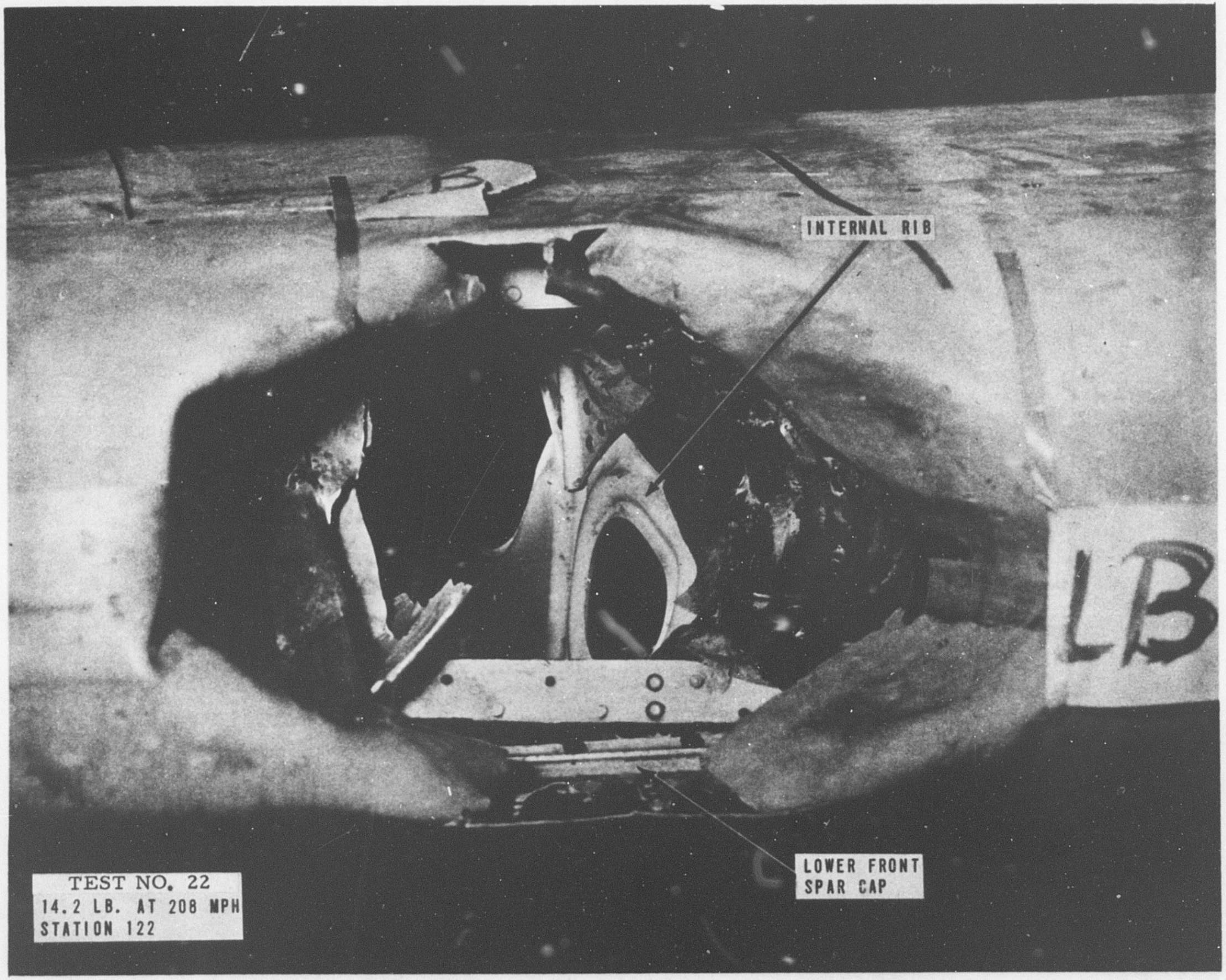


FIG. 4 BIRD STRIKE DAMAGE TO LEADING EDGE OF THE HORIZONTAL STABILIZER OF A PISTON-ENGINE TRANSPORT AIRPLANE

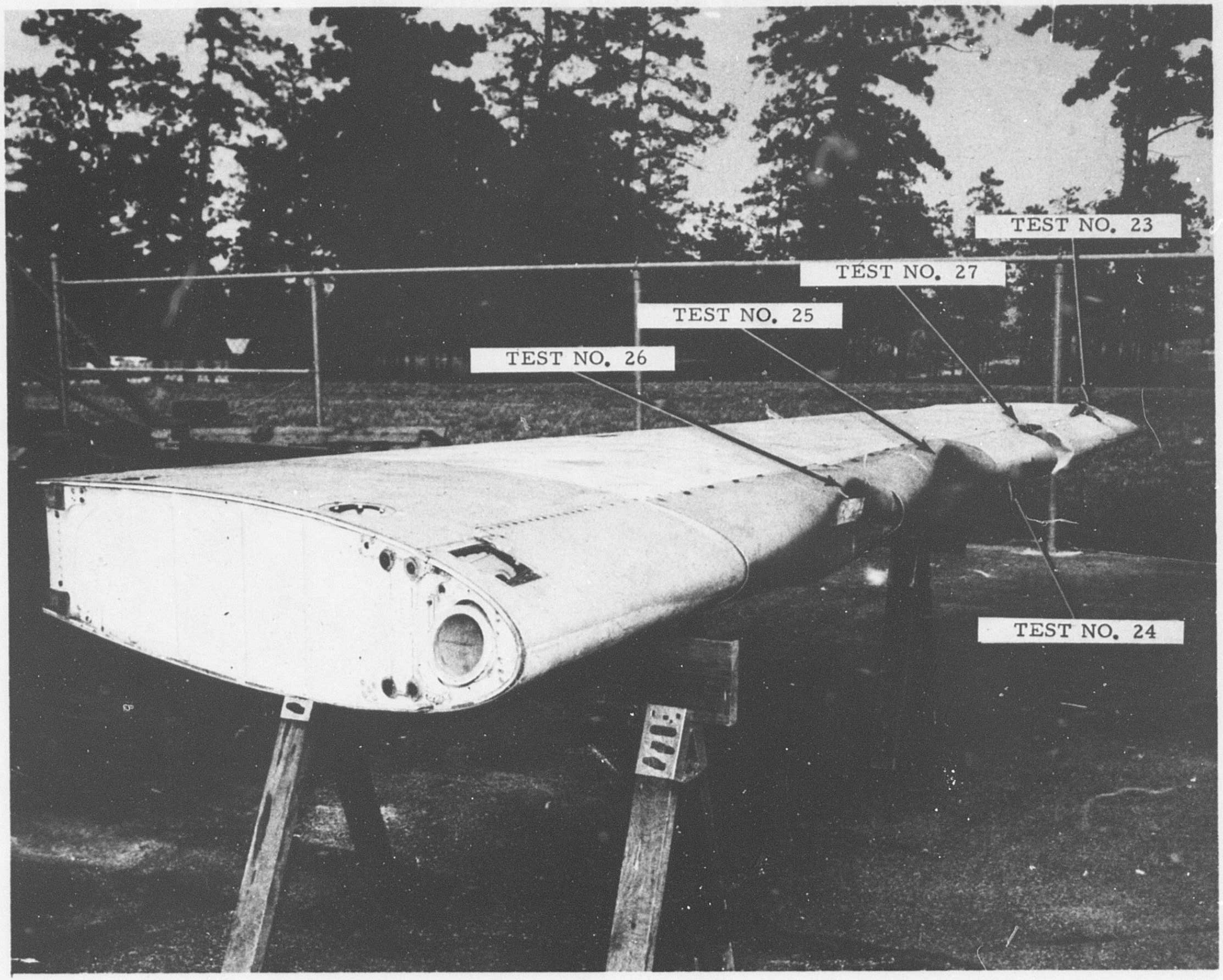


FIG. 5 BIRD STRIKE RESULTS ON A MODIFIED HORIZONTAL STABILIZER OF A PISTON-ENGINE TRANSPORT AIRPLANE

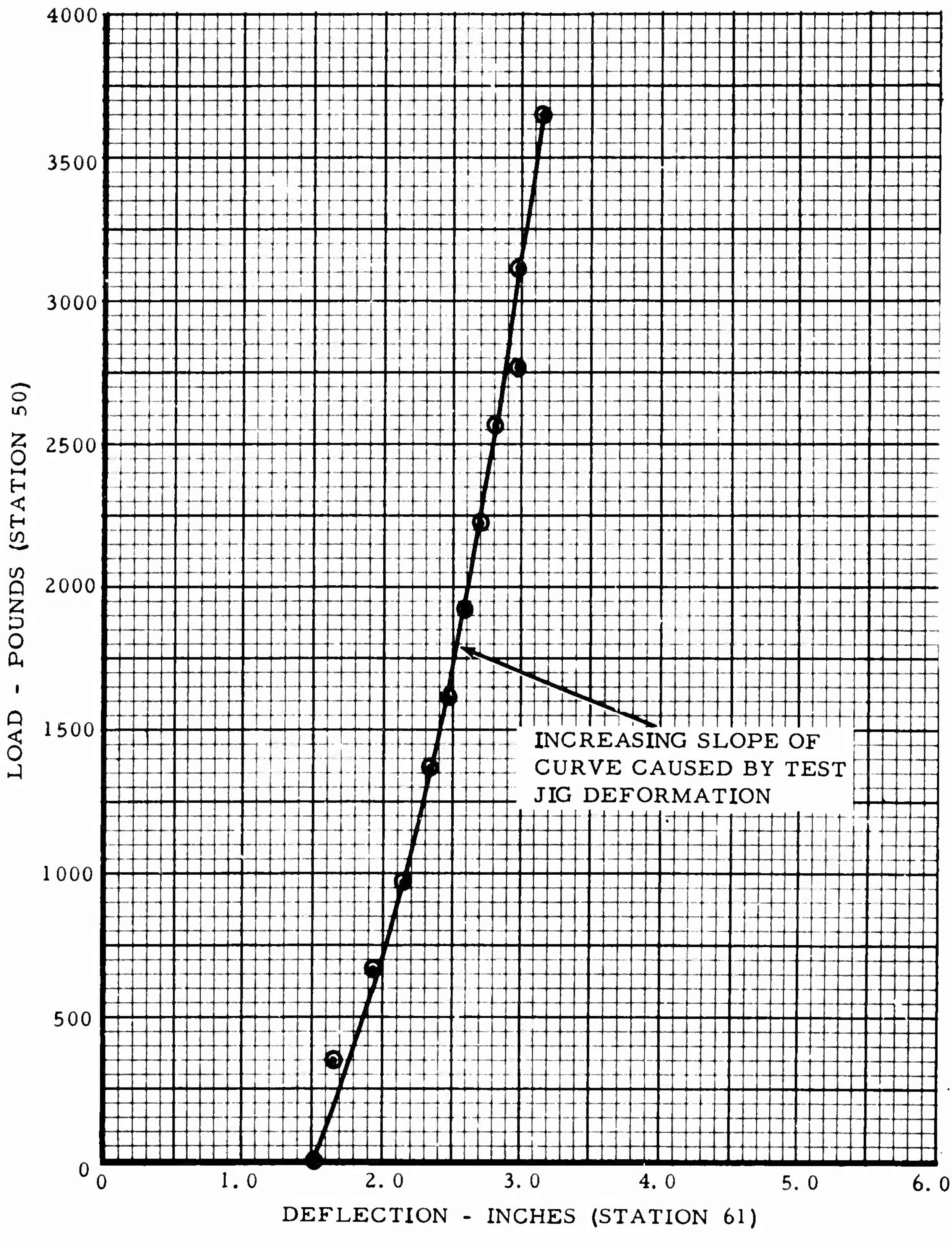


FIG. 6 RESULTS OF LOAD-DEFLECTION TEST MADE AFTER TEST NO. 31 ON A TURBOPROP TRANSPORT HORIZONTAL STABILIZER

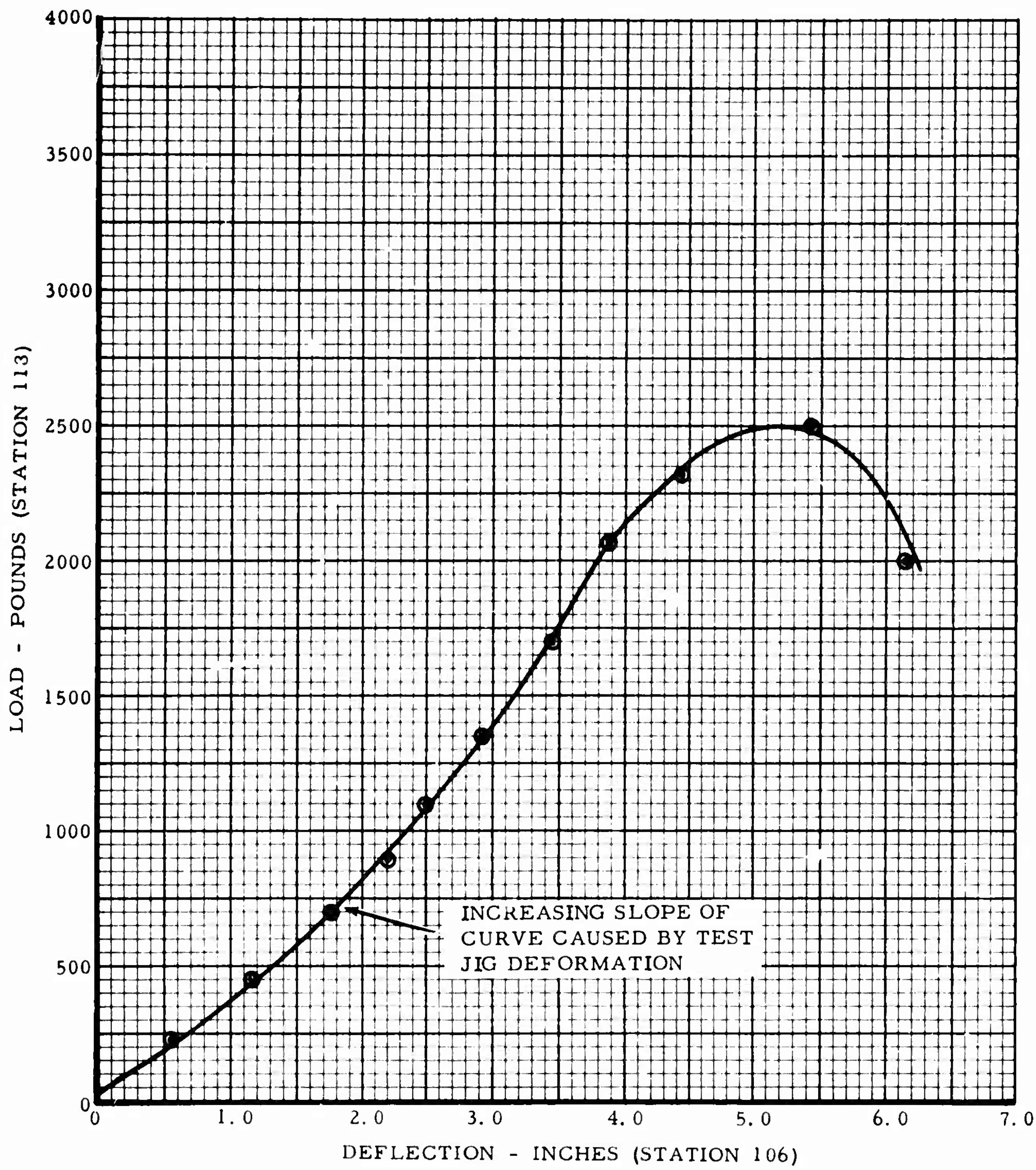


FIG. 7 RESULTS OF LOAD-DEFLECTION TEST MADE AFTER TEST NO. 32 ON A TURBOPROP TRANSPORT HORIZONTAL STABILIZER

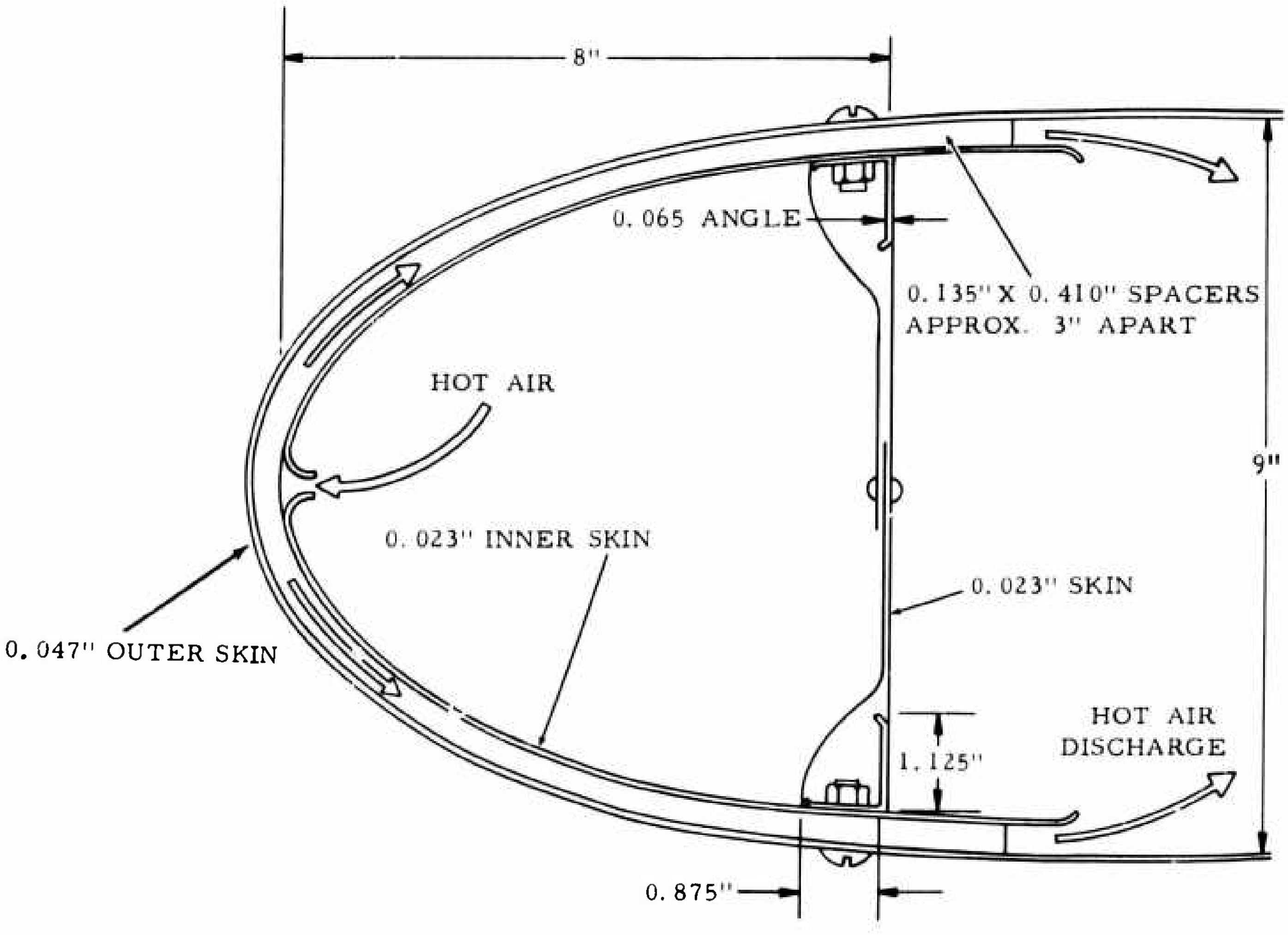
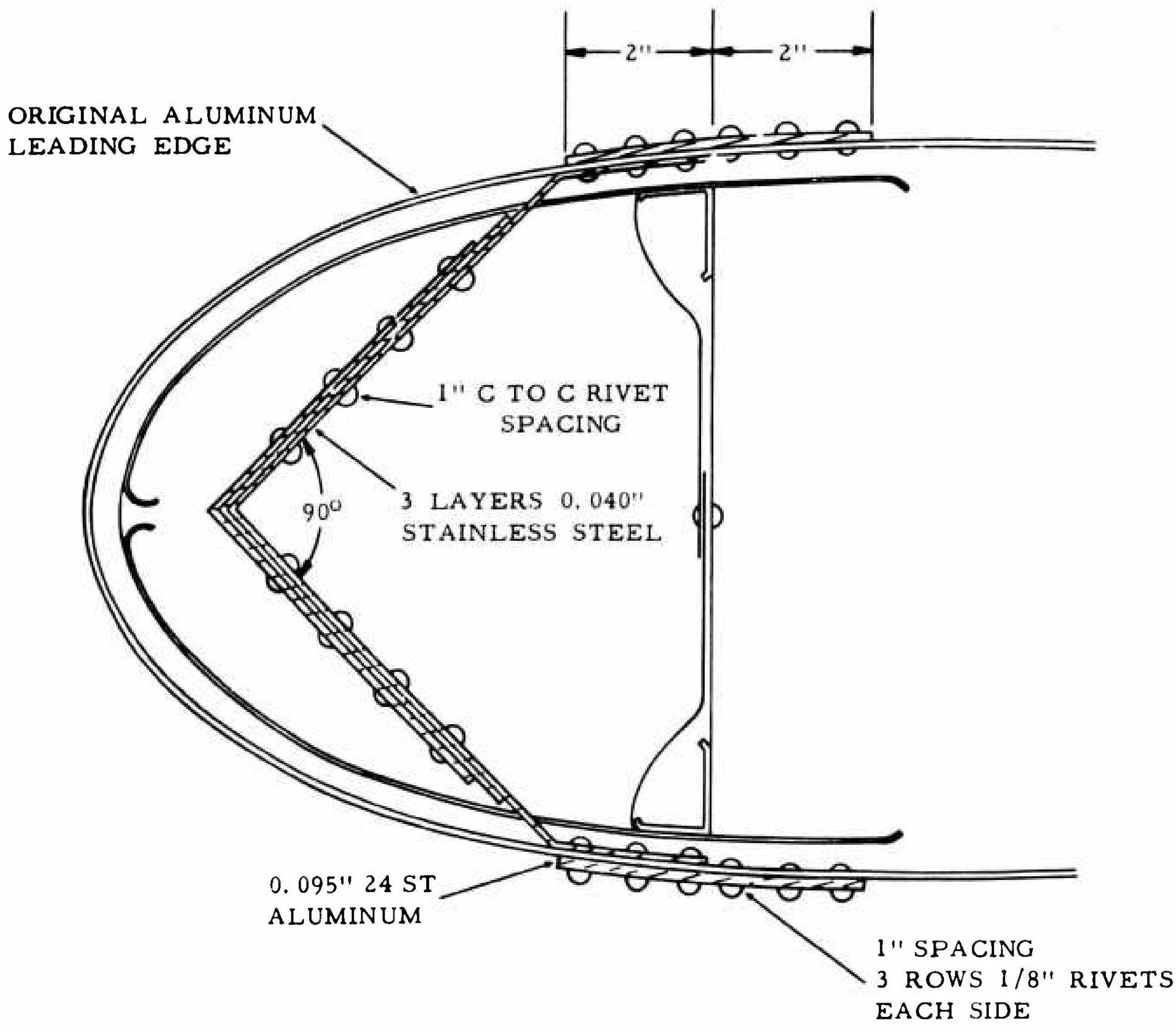
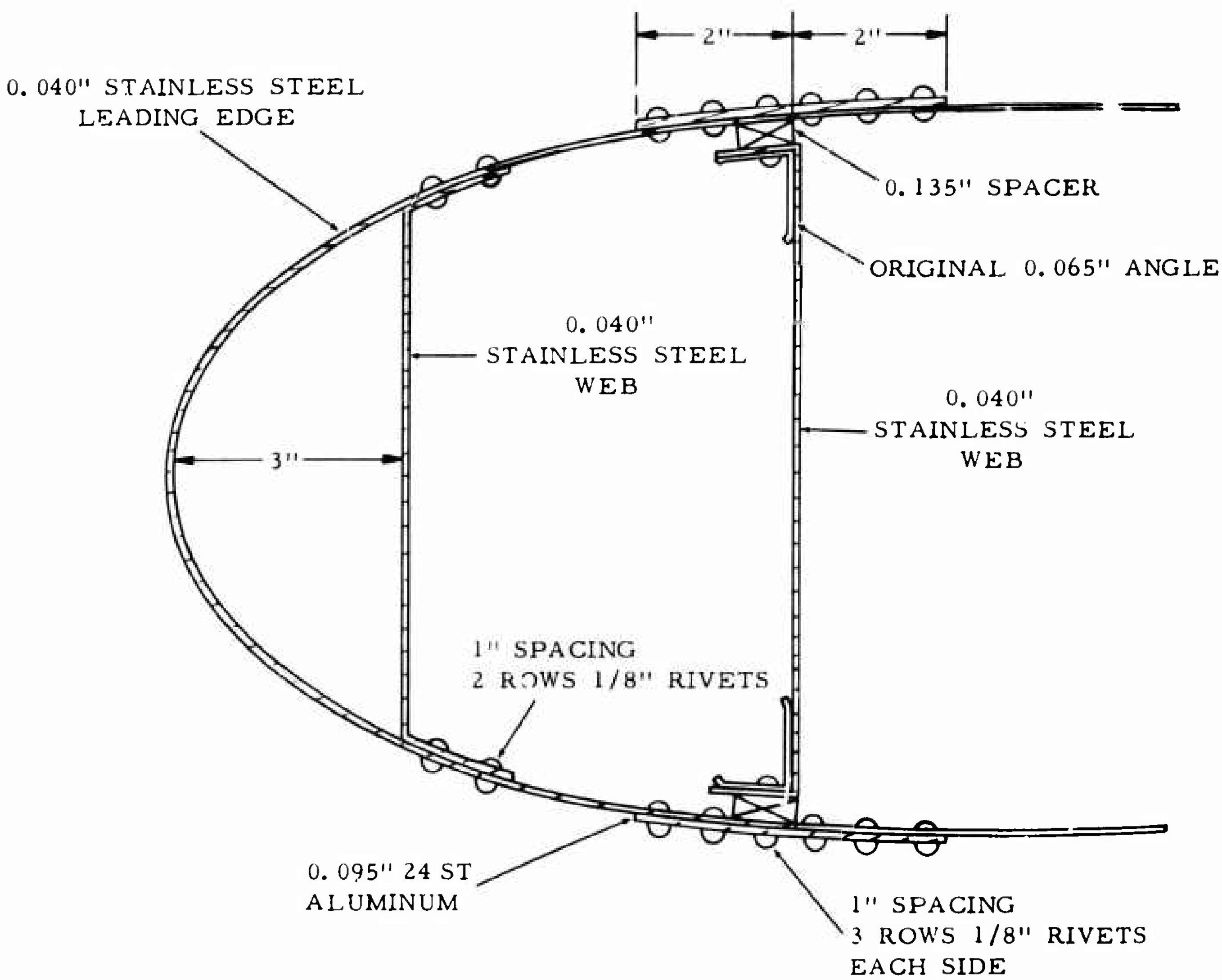


FIG. 8 ORIGINAL LEADING EDGE ON HORIZONTAL STABILIZER OF A TURBOPROP TRANSPORT AIRPLANE



WEIGHT: 5.5 POUNDS PER FOOT

FIG. 9 LAMINATED STAINLESS STEEL SPLITTER PLATE MODIFICATION ON A TURBOPROP TRANSPORT AIRPLANE



WEIGHT: 4.5 POUNDS PER FOOT
ORIGINAL LEADING EDGE WEIGHED 1.8 POUNDS PER FOOT
NET ADDED WEIGHT 2.7 POUNDS PER FOOT

FIG. 10 STAINLESS STEEL LEADING EDGE WITH TWO STAINLESS STEEL WEBS ON A TURBOPROP TRANSPORT AIRPLANE

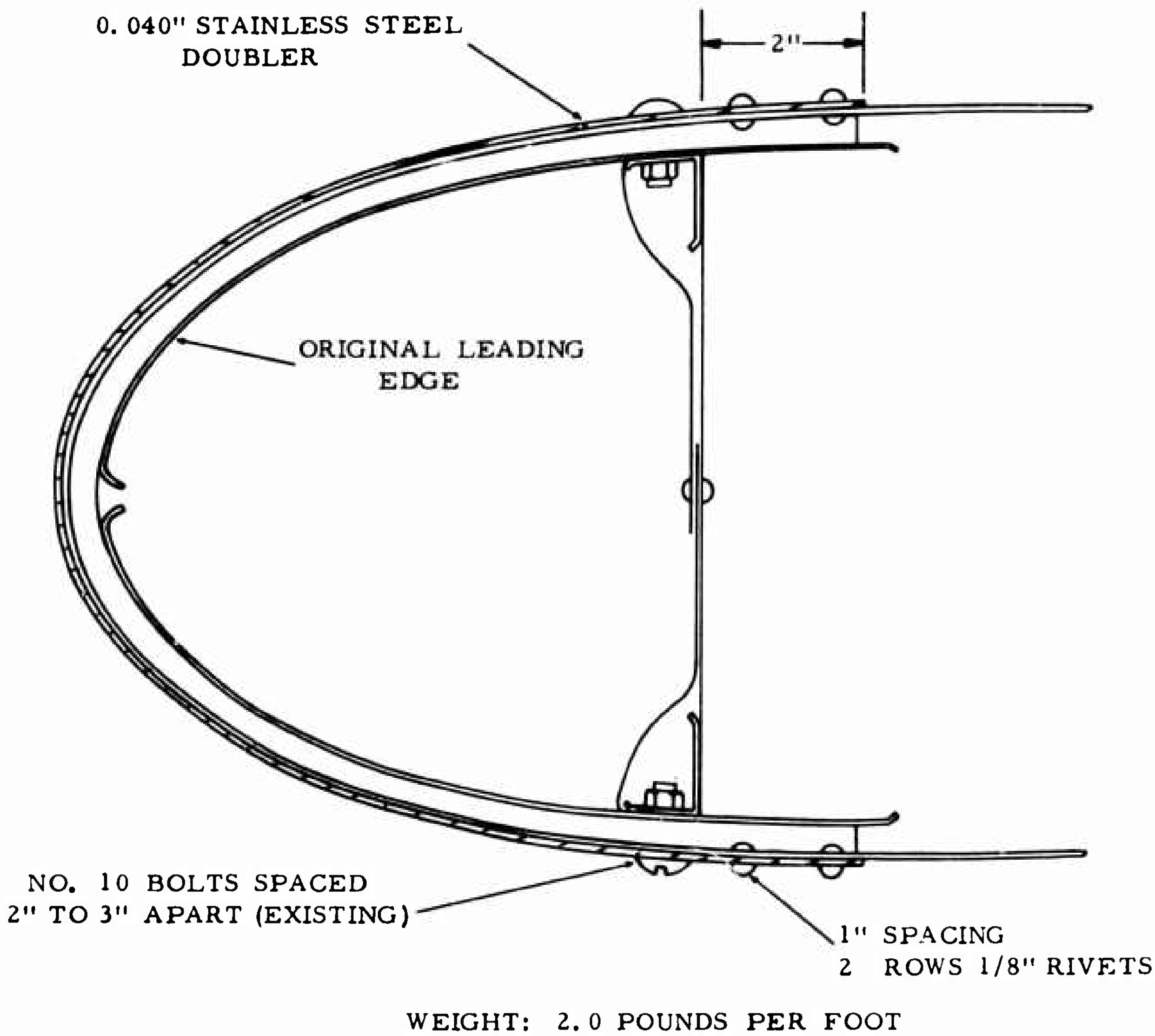


FIG. 11 STAINLESS STEEL DOUBLER OVER LEADING EDGE ON A TURBOPROP TRANSPORT AIRPLANE

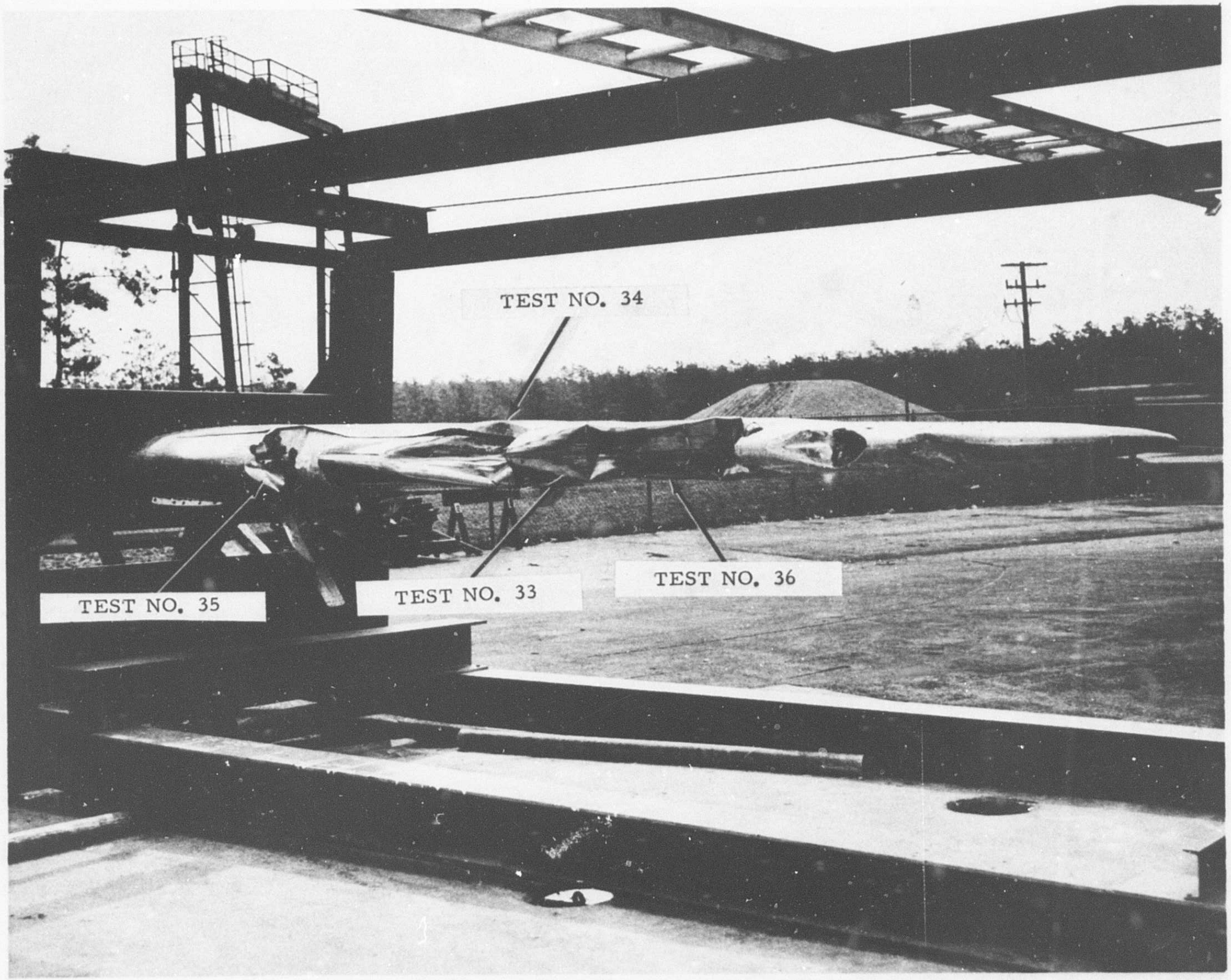


FIG. 12 HORIZONTAL STABILIZER OF A TURBOPROP TRANSPORT AIRPLANE AFTER BIRD STRIKES

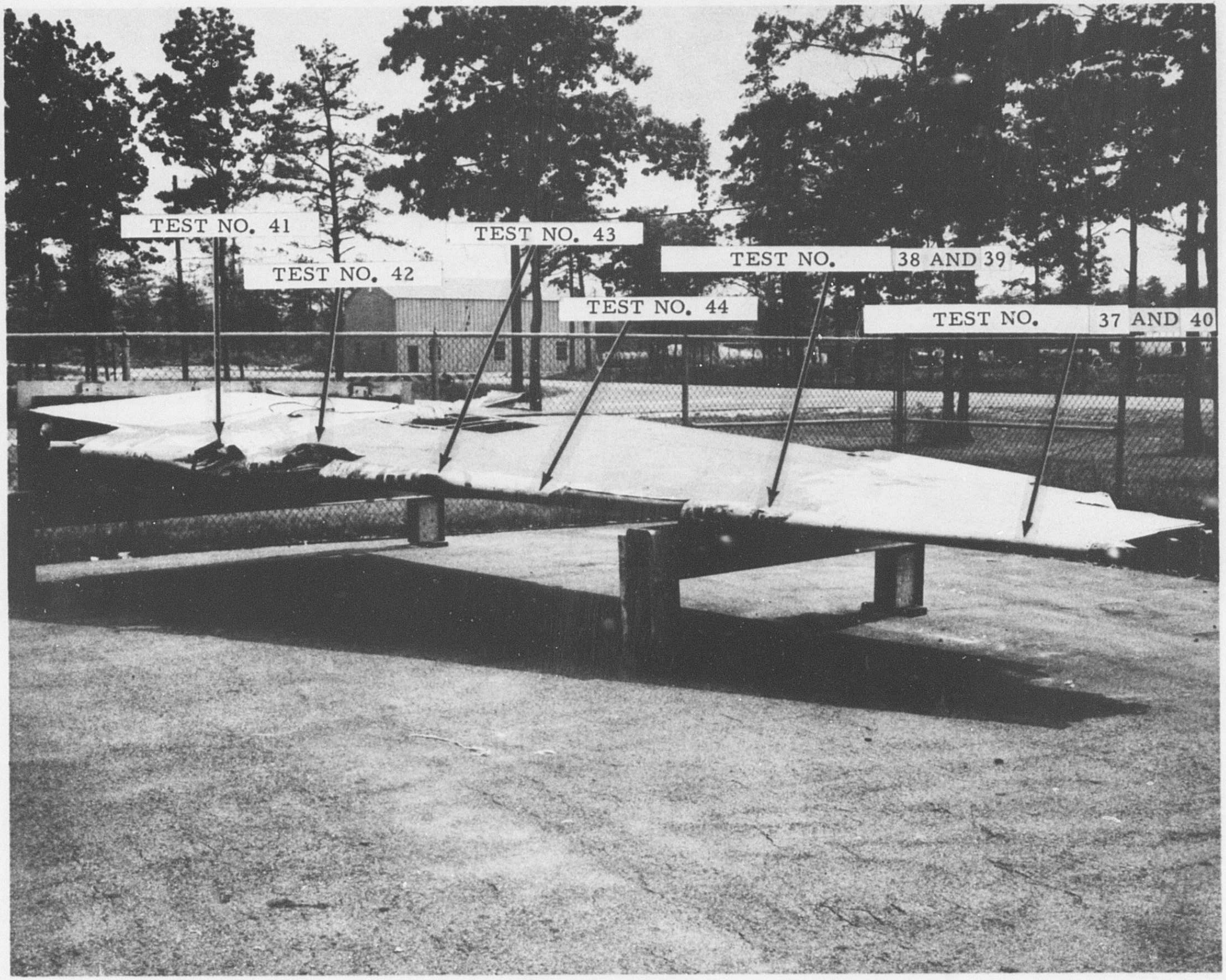


FIG. 13 VERTICAL STABILIZER OF A JET-TYPE TRANSPORT AIRPLANE AFTER BIRD STRIKES

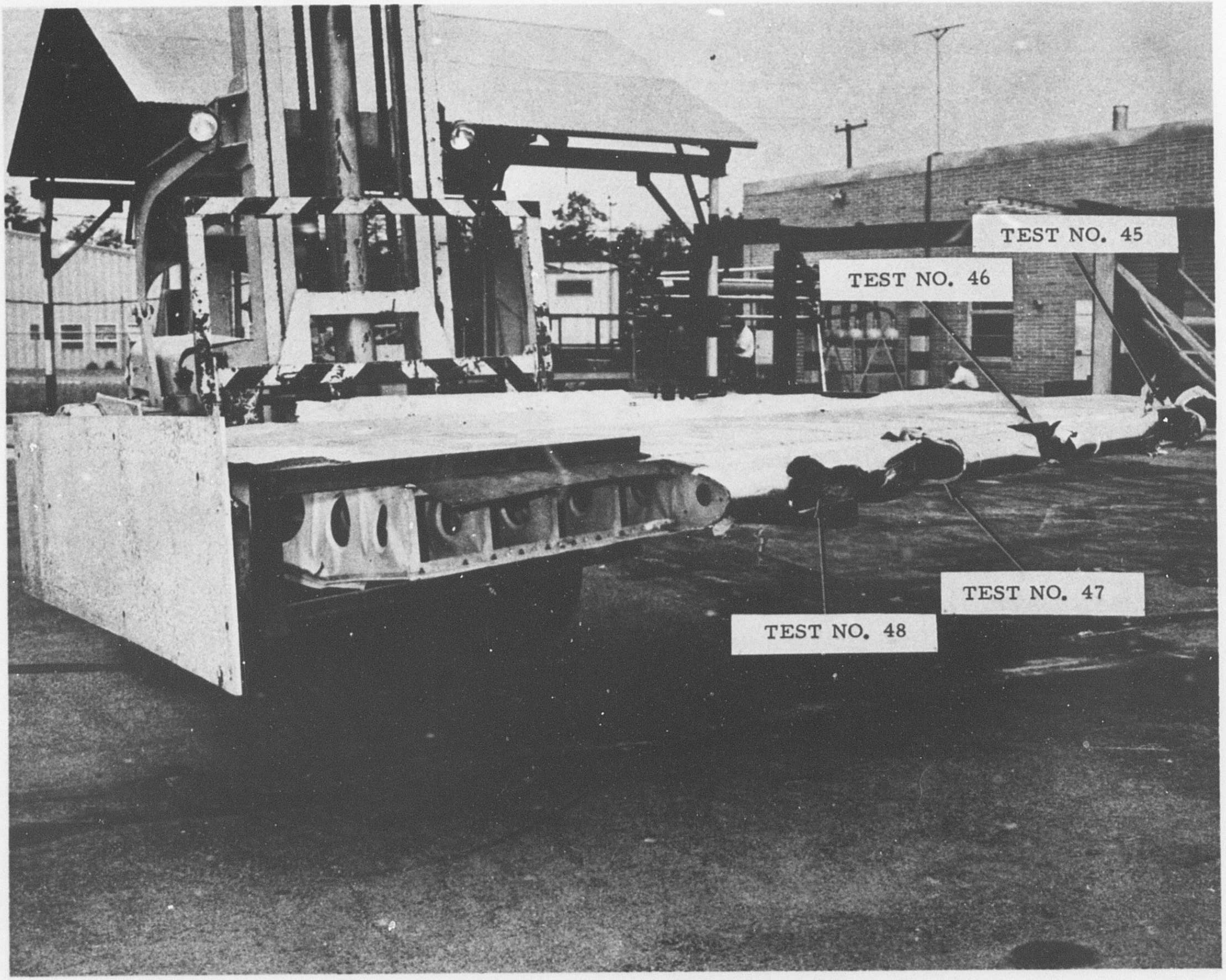


FIG. 14 HORIZONTAL STABILIZER OF A JET-TYPE TRANSPORT AIRPLANE AFTER BIRD STRIKES